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Biological Report 82(11.123)
December 1989

TR EL-82-4

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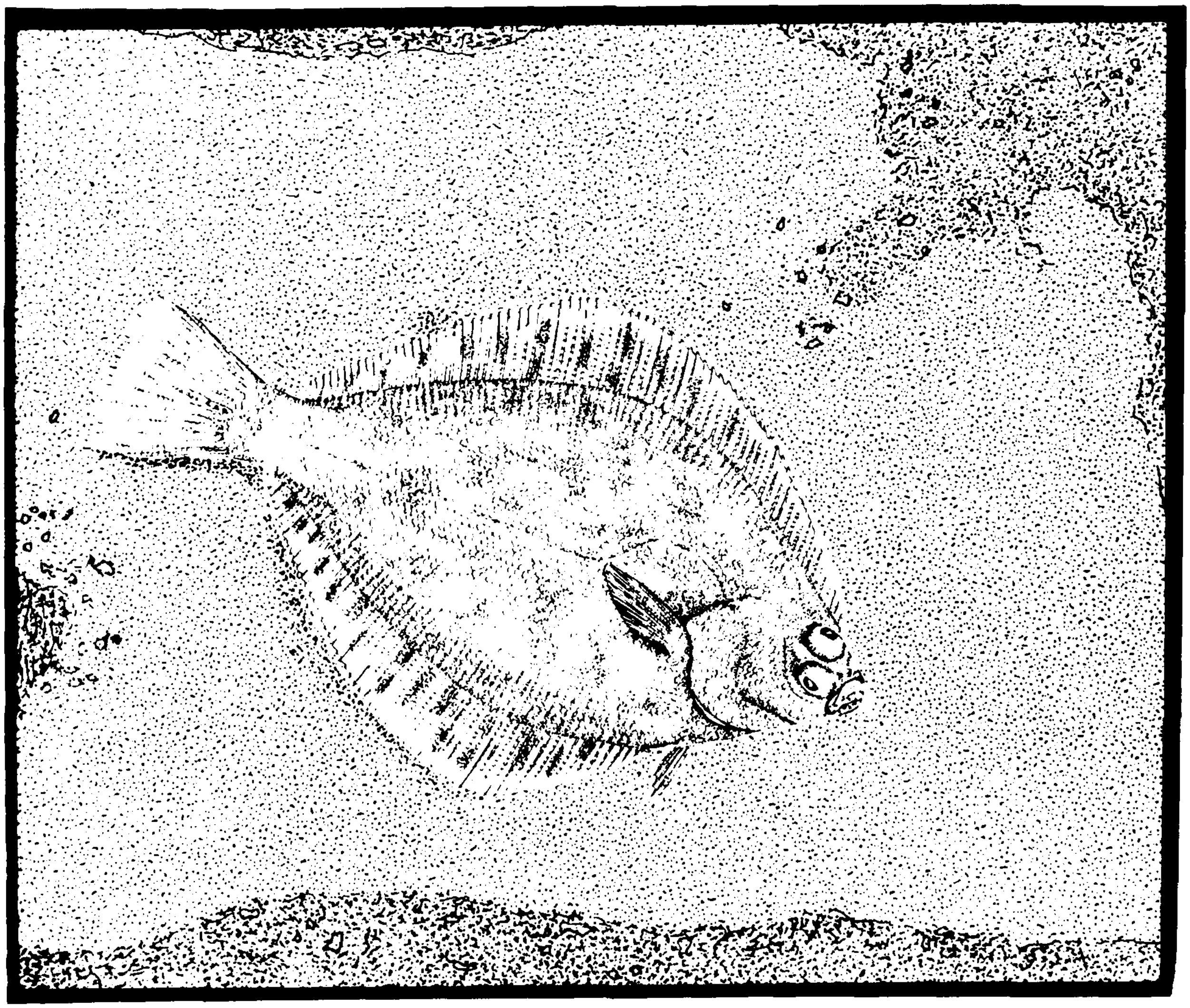
DOVER AND ROCK SOLES



Coastal Ecology Group
Waterways Experiment Station

Fish and Wildlife Service

U.S. Department of the Interior

U.S. Army Corps of Engineers

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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)

DOVER AND ROCK SOLES

by

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Performed for
Coastal Ecology Group
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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Suggestions or questions regarding this report should be directed to one of the following addresses.

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Attention: WESER-C
Post Office Box 631
Vicksburg, MS 39180

CONVERSION TABLE

Metric to U.S. Customary

Multiply	*By*	*To Obtain*
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (° C)	1.8 (° C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces	28.35	grams
pounds (lb)	0.4536	kilograms
pounds	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (° F)	0.5556 (° F - 32)	Celsius degrees

CONTENTS

FIGURES

ACKNOWLEDGMENTS

Special thanks are extended to the Canadian Department of Fisheries and Oceans for permission to reproduce Figures 1 and 2 from their Bulletin 180 of the Fisheries Research Board of Canada. I appreciate the permission given by Mary Yoklavich and Ellen Pikitch to refer to data in their unpublished manuscript. Robert Wolotira of the National Marine Fisheries Service provided a review. William Barss also reviewed the manuscript and was especially helpful in locating unpublished reports from the Oregon Department of Fish and Wildlife. Richard Bakkala generously provided reports on rock sole from the Northwest and Alaska Fisheries Center of the National Marine Fisheries Service. I appreciate the help provided by Jeannine Horton who redrew several of the figures. Sandy Enschede typed early drafts of the manuscript and was generally helpful in completing this report.

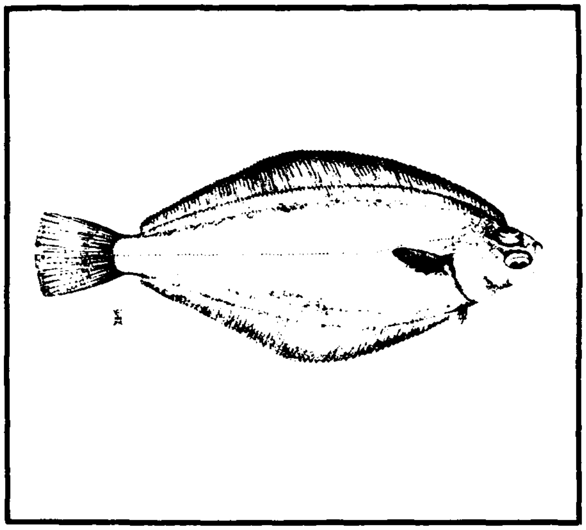

Figure 1. Dover sole (*Microstomus pacificus*) (illustration from Hart 1973).

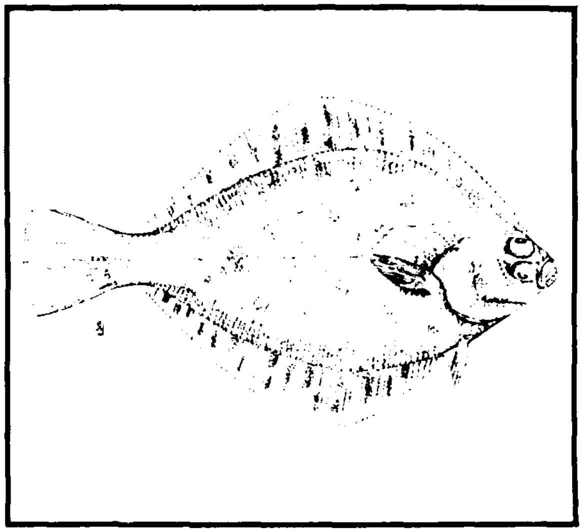

Figure 2. Rock sole (*Lepidopsetta bilineata*) (illustration from Hart 1973).

DOVER AND ROCK SOLES

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . *Microstomus pacificus* (Lockington).
Preferred common name . . . . . . Dover sole (Figure 1).
Other common names . . . . Slime sole, slippery sole, smear dab, tongue sole, rubber sole, short-finned sole.

Scientific name . . . . *Lepidopsetta bilineata* (Ayres).
Preferred common name . . . . . . Rock sole (Figure 2).
Other common names . . . Roughback sole, broadfin sole, gravel sole.
Class . . . . Osteichthyes
Order . . . . Pleuronectiformes
Family . . . . Pleuronectidae

Geographic ranges:

Dover sole (Figure 3): Occurs along the Pacific Coast from northern Baja California to the Bering Sea (Hart 1973). Most common on the southern California continental shelf (Mearns and Harris 1975), and off northern California, Coos Bay, Oregon, and the Columbia River (Demory 1975). Moderately abundant off northern Washington, British Columbia, and the western Shumagin Island area (Demory 1975; Ronholt et al. 1986). Caught incidentally while fishing for other species in the eastern Bering Sea and the Aleutian Islands region (Bakkala et al. 1981; Walters and Halliday 1987b).

Recorded from the surface (Hart 1973) to a depth of 1,189 m (Allen and Mearns 1976). Adults rarely found shallower than 36 m (Demory 1975) and most of the commercial catch off northern California comes from depths of 82-823 m (Allen and Mearns 1976). Strongly prefers silt, mud, and muddy-sand bottom (Demory 1975; Demory et al. 1976b; Barss et al. 1977). Concentrates near deep-water municipal wastewater outfalls off southern California (Mearns and Harris 1975; Allen and Mearns 1976).

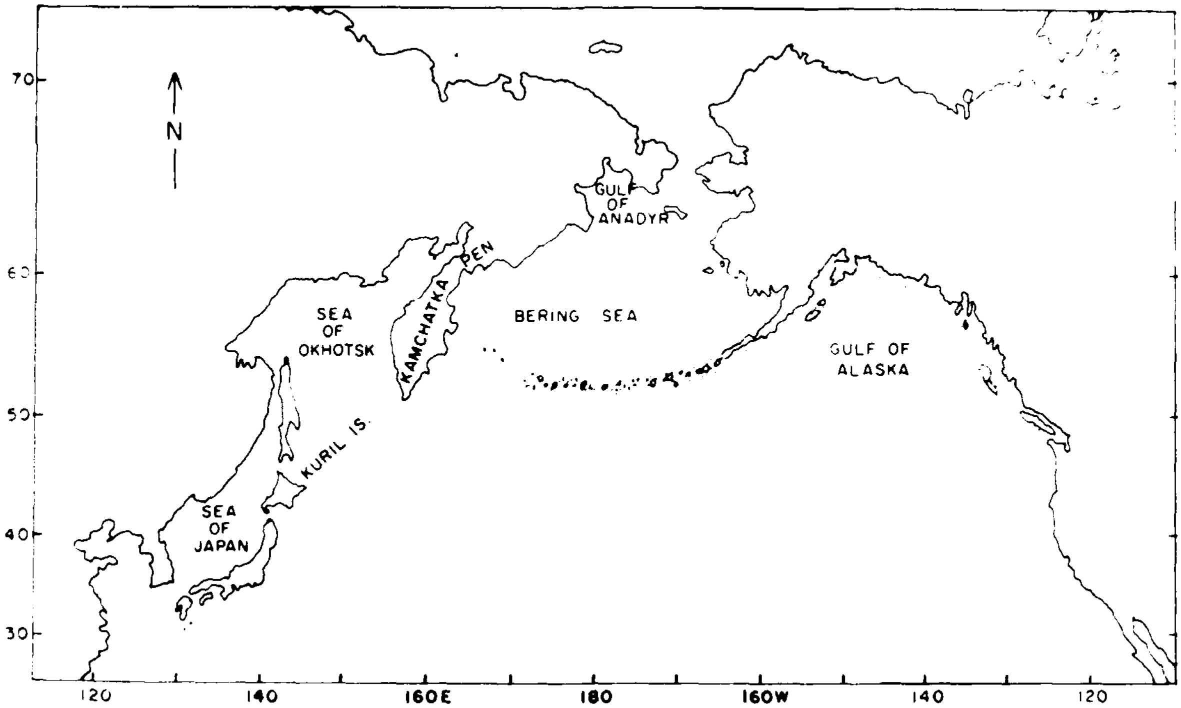

Figure 3. Distribution of the Dover sole.

Rock sole (Figure 4): Distributed from southern California to the Gulf of Alaska, along the Aleutian Chain, and as far north as the Gulf of Anadyr in the Bering Sea; then south off Kamchatka, the Kurile Islands, the eastern Okhotsk Sea, the Sea of Japan, and the east coast of Korea (Roedel 1953; Alton and Sample 1976). Centers of abundance off Kamchatka, in the southeastern Bering Sea and the western Gulf of Alaska, and along the coast of British Columbia (Alton and Sample 1976). Occurs from the surface to 732 m, but is a shallow-water species scarcely below 300 m (Alverson et al. 1964; Hart 1973; Ronholt et al. 1986). Commercial fishery concentrated at depths of 18-73 m in British Columbia (Forrester 1969), and from shallow depths to slightly over 200 m in Alaskan waters (Alton and Sample 1976; Ronholt et al. 1986). Found on mud and sand substrata in the Bering Sea, on sandy or gravel bottom along the Pacific coast, and on rocky or firm, rapidly-sloping bottom in Puget Sound, Washington, waters (Nishishimamoto 1958; Alverson 1960; Ronholt et al. 1986).

MORPHOLOGY/IDENTIFICATION AIDS

Dover Sole

Body elongate, slender, compressed; caudal peduncle very short (Figure 1). Head slender, short; mouth terminal, small, asymmetrical, gape narrow, nearly equal on each side; teeth chiefly on blind side of jaws, never more than three in either jaw on eyed side; snout bluntly rounded; eyes small, lower eye in advance of upper eye; gill opening not extending above base of uppermost pectoral fin ray (Clemens and Wilby 1961). Eyes dextral, with few exceptions (Follett et al. 1960). Lateral line nearly straight, with a short unconnected supratemporal branch (Norman 1934). On eyed side, color is rich and uniform in shades of

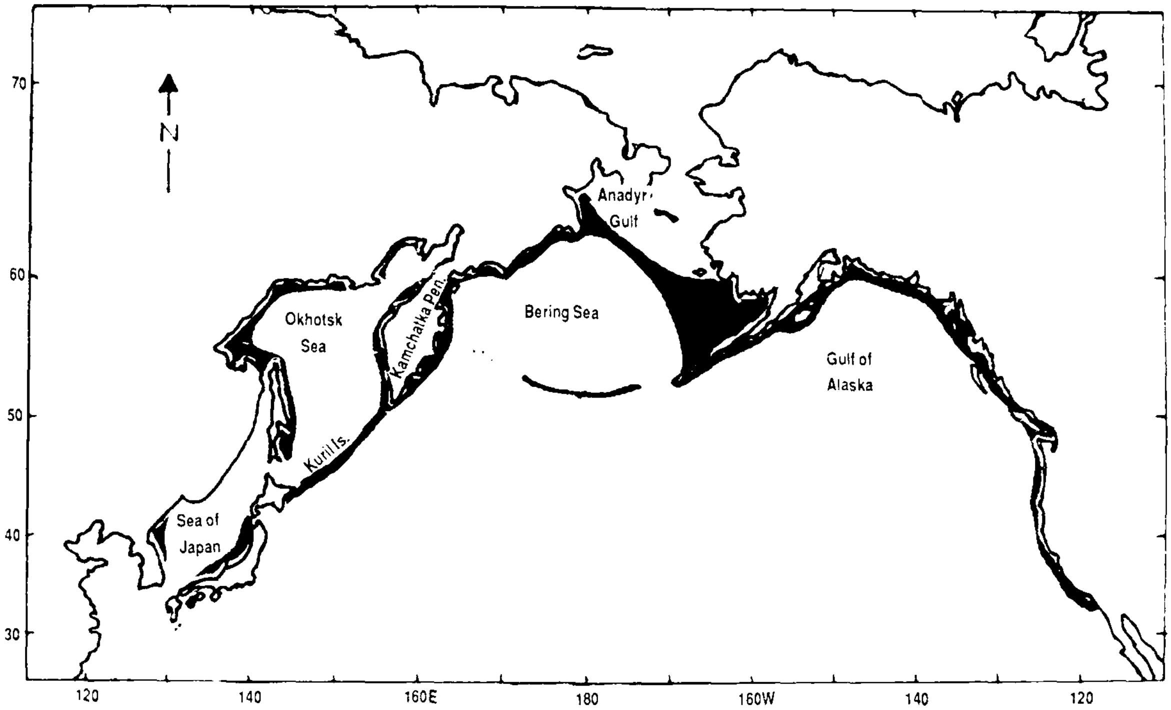

Figure 4. Distribution of rock sole (Alton and Sample 1976).

brown or mottled; blind side light to fairly dark gray; dusky on fins, especially near tips. Length to 71 cm total length (TL) and weight to 3.36 kg for females; males are smaller. Secretes large amounts of slime; body flaccid (Hagerman 1952; Hart 1973).

Rock Sole

Body elongate, deeply ovate, compressed, dextral. Head deep; mouth terminal, small, asymmetrical, gape narrow; teeth chiefly on blind side of jaws; snout bluntly rounded (Figure 2). Maxillary extends to forward part of lower eye. Eyes small, lower eye slightly in advance. Caudal peduncle moderate. Lateral line with an abrupt high arch over pectoral fin and with a short supratemporal accessory branch (Roedel 1953; Clemens and Wilby 1961; Wilimovsky et al. 1967; Hart 1973). Rough tuberculated scales on the eyed side of the body. Usually deep brown on eyed side, frequently mottled with dark blotches, occasionally with scattered small red spots or pale blotches, reddish yellow to white on blind side; caudal and anal fins with dark blotches or bars (Roedel 1953; Clemens and Wilby 1961). Females reach a length of 60 cm TL; males 53 cm (Hart 1973). Weigh 2.3-2.7 kg (Norman 1934; Roedel 1953).

REASON FOR INCLUSION IN THE SERIES

The Dover sole has been an important component of the California trawl fishery since its inception in 1876 (Hagerman 1952). In Oregon, Dover sole made the largest contribution to total biomass of flatfishes landed commercially (Demory et al. 1976a). The excellent quality of the flesh, fresh or frozen, and long shelf life have made it one of the most important of the small flatfishes on the Pacific Coast (Hart 1973). Dover sole are commercially important from Santa Barbara, California, to British Columbia (Allen and Mearns 1976).

The rock sole is listed as one of the key species in Washington inside waters where it is the target of commercial trawl fisheries and is caught by recreational anglers (Pederson and DiDonato 1982). The rock sole is relatively abundant north of Coos Bay, Oregon (Cannon 1953). It is listed by Browning (1974) as a principal flatfish species in the North Pacific commercial fisheries. The estimated maximum sustained yield for rock sole in the eastern Bering Sea and the Aleutian Islands region was 100,000 t in 1987 (Walters and Halliday 1987a).

LIFE HISTORY

Reproduction

Dover sole females off northern California and Oregon first reach maturity at 33 cm TL; at 38 cm, 50% are mature; and at 45 cm and 11 years of age all are mature (Hagerman 1952; Harry 1959; Demory 1975). Some males mature at 30 cm TL, and all mature by 39 cm and 7 years of age (Hagerman 1952). Frey (1971) indicated that maturity starts at age 5 off northern California. Age at maturity probably varies by region and increases progressively from south to north. Recently, Yoklavich and Pikitch (1988) found that all Dover sole collected off northern Oregon were mature at 32 cm TL; the smallest mature fish was 24 cm. They suggested that difficulties in differentiating post-spawning, inactive, mature ovaries from immature ones may have contributed to the size at maturity discrepancies.

Dover sole spawn at specific sites in offshore waters between 80 and 732 m (Demory 1975; Garrison and Miller 1982; Hirschberger and Smith 1983). The spawning period varies by region and occurs from January to August in the Gulf of Alaska and from November through March off Washington, Oregon, and California, with January and February being the peak months (Harry 1959; Demory 1975; Garrison and Miller 1982; Hirschberger and Smith 1983). Fecundity is a function of size and ranges from 37,000 ova for a 36.0 cm TL fish, to 265,800 ova for a 57.5 cm TL fish (Harry 1959; Frey 1971) The length-fecundity relationship is illustrated in Figure 5 for Dover sole captured off Oregon (Harry 1959). Fecundity estimates for 42-64 cm TL Dover sole captured off northern California (Hagerman 1952) are slightly higher than for Oregon fish of the same size.

Female rock sole from Puget Sound, Washington, mature in their fourth or fifth year, while males reach maturity in their third year (Smith 1936). In nearby British Columbia waters, Forrester (1969) observed mature females at 31 cm TL and mature males at 28 cm TL. These lengths represent age-4 fish. No sexual dimorphism is apparent (Alton and Sample 1976).

Rock sole spawn during winter and spring throughout their range (Alton and Sample 1976). In British Columbia, spawning is believed to take place during late winter and early spring (Forrester 1969). In winter in the Shumshu Islands of the Okhotsk Sea, large sexually mature rock sole stay at depths of 125-250 m (Shvetsov 1978). In Puget Sound, Washington, mature rock sole were captured at 150 m in February 1950, but they usually

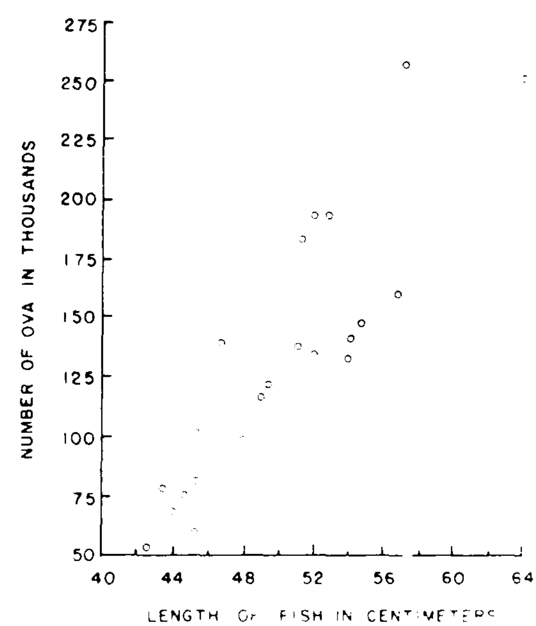

Figure 5. Fecundity-length relationship for Dover sole captured off Oregon during the winter of 1947-48 (Harry 1959).

occurred in water less than 55 m deep (Nishishimamoto 1958). It thus appears that fish move into deeper water in winter and spring to spawn. Rock sole produce about 0.4 million ova at 35 cm TL and 1.3 million at 46 cm TL (Forrester 1969).

The eggs and larvae of Dover sole are buoyant and pelagic (Norman 1934; Hagerman 1952). Diameters of ovarian eggs average 2.33 mm, ranging from 2.05 to 2.57 mm (Hagerman 1952). The yolk is homogeneous and oil globules are lacking. Larvae are about 6.5 mm standard length (SL) at hatching. They become deep bodied (Figure 6) and remain in the larval stage until about 50 mm SL. Two spines develop on the back of the head of advanced larvae. Certain meristic features simplify identification of Dover sole larvae: caudal rays, 21-22; vertebrae, 50-53; dorsal rays, 94-106; and anal rays, 80-88. Larvae were captured in standard ichthyoplankton hauls (this method is described in Kramer et al. 1972) off California chiefly from April through July (Ahlstrom and Moser 1975), but were taken off Oregon with mid-water trawls and plankton nets throughout the year (Pearcy et al. 1977). The occurrence of advanced larvae during the spawning season indicates that Dover sole larvae are pelagic for at least a year (Pearcy et al. 1977).

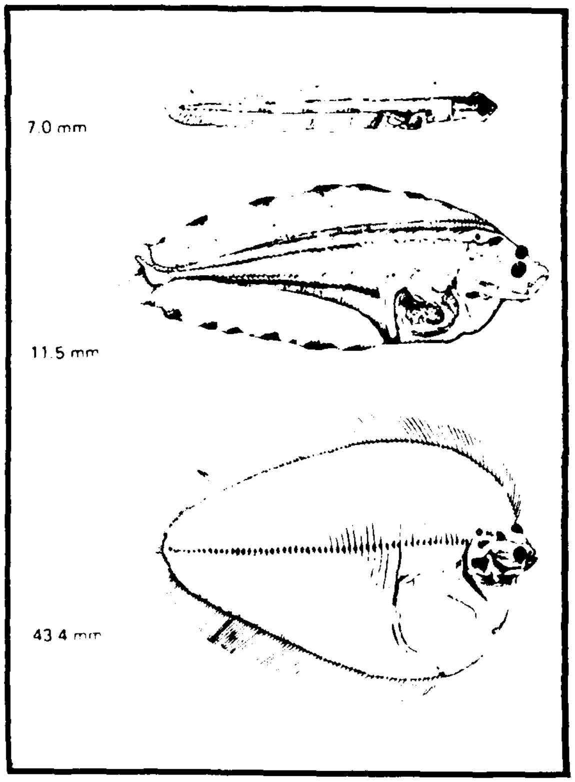

Figure 6. Larval stages of Dover sole (Ahlstrom and Moser 1975).

Dover sole larvae are widely distributed off Oregon; peak Isaacs-Kidd midwater trawl (IKMWT) catches are at 46 km and fish occur at distances as great as 550 km offshore (Pearcy et al. 1977). Off Baja California, Dover sole larvae have been caught with IKMWT as far as 840 km offshore (Berry and Perkins 1966). North-south movement off Oregon is more or less random, but more large larvae are found near the continental shelf and slope (where they eventually settle) than in inshore waters (Pearcy et al. 1977). Dover sole off Oregon appear to take up benthic life on the continental shelf in January and February; they are then about 1 year old and are less than 50 mm SL (Demory 1975; Pearcy et al. 1977).

Small Dover sole (<18 cm TL) occur on the continental shelf off the Oregon-southern-Washington coast mostly between 55 and 146 m (Demory 1971). In February, most occur at depths greater than 128 m and none occur at depths less than 73 m. During May, July, and August, most small fish are found between 55 and 90 m. In November, they mostly occur between 91 and 108 m (Demory 1971). Although there is overlap in the depth distribution of smaller and larger Dover sole, it appears that "adults" are often distributed in deeper water, with the possible exception of July and February. Demory's (1971) study, however, was completed before Oregon's deep water Dover sole fishery was established. The deep water fishery has produced mostly males except for catches of concentrated mature males and females in winter.

The yellowish-orange eggs of rock sole are demersal and adhesive and have a diameter that averages 0.92 mm and ranges from 0.87 to 1.00 mm (Forrester 1964a, 1964b; Ahlstrom et al. 1984). The yolk is homogeneous, and oil

globules are lacking. Larvae range from 3.4 to 5.0 mm SL when hatched and are 17.7-20.0 mm SL at transformation. As in the Dover sole, identification is facilitated by meristic features: caudal rays, 18-19 (12 are branched); vertebrae, 39-42; dorsal rays, 65-84; and anal rays, 50-65 (Pertseva-Ostroumova 1961; Ahlstrom et al. 1984).

Young rock sole in Kamchatka swim on their sides and assume their bottom-dwelling existence at about 20 mm SL (Pertseva-Ostroumova 1961). They occur in shallow water on beaches in some localities (Hart 1973). Little is known of the whereabouts of rock sole in their first year of life on the seafloor, but by age 1 they are found with the adults (Forrester 1969; Alton and Sample 1976).

Migration and Movement of Adults

Dover sole adults undergo annual bathymetric migrations in Pacific Northwest waters. From May through October the fish are generally found in shallow waters less than 150 m deep. After October, fish move back to deeper waters; this return coincides with the principal spawning season of November through March with a peak in January and February (Alverson 1960; Westrheim and Morgan 1963; Barss 1982; Quirollo and Kalvass 1987; Barss and Demory 1988).

Dover sole exhibit very little north-south seasonal migration in the Pacific Northwest. Fargo et al. (1985) recovered 745 of 5,145 Dover sole tagged off northern Hecate Strait, British Columbia, and reported negligible dispersal of about 0.4% per year. Of 260 tagged fish recovered off Willapa, Washington, only 7 were recaptured more than 48 km from the original tagging area. Maximum migrations were 161 km north and 579 km south (Westrheim and Morgan 1963). Barss and Demory (1988) reported on the recovery of 2,194 Dover sole out of 22,336 tagged off Oregon and Washington in eight experiments during 1948-75. Maximum time at liberty was 22 years. They found only modest north-south movement with 98% of the recaptures occurring within 93 km of the tagging site. Of 1,235 tagged Dover sole recovered off southern Oregon and northern California by Quirollo and Kalvass (1987), only 13 were recaptured outside the original tagging area. The mean movement from the point of release was 19 km. A Dover sole tagged off Mad River in northern California was at liberty 2,234 days when recaptured and had a net movement of only 40.2 km (Best 1957). These small movements suggest a limited exchange of stocks among adjacent offshore areas from northern California to British Columbia.

There is no indication that bathymetric migrations of rock sole are as extensive as those of some other flounders in Pacific Northwest waters. However, there is some evidence that rock sole move to shallow water (18-27 m) for the summer and return to deep water for the winter (Alverson 1960: Forrester 1969; Shvetsov 1978). Rock sole off Shumshu Islands in the Okhotsk Sea overwinter on the edge of the continental slope at a depth of 125-320 m from December to April. From April to June, the fish return to the continental shelf to depths of 50-120 m (Shvetsov 1978). Shvetsov (1978) believes that the movement from winter to spring grounds is in response to warming temperatures in the shallow waters, whereas the summer movements are related to distribution of prey on the seafloor rather than to water temperature. The principal stimulus for moving to deep water in winter is the peaking of physiological condition prior to spawning which results in diminished feeding (Shvetsov 1978).

All rock sole tagged in Hecate Strait of British Columbia were recovered in the general vicinity of the tagging and previous capture sites (Forrester and Thomson 1969). This apparent lack of significant movement suggests the existence of several discrete subpopulations in the northwest (Forrester 1969).

GROWTH CHARACTERISTICS

Dover sole generally were aged by counting annuli on the surface of scales or otoliths prior to about 1980. Scales were collected from the central portion of the eyed side of the body, mounted between glass slides, and read under magnification with transmitted light. Otoliths

(sagittae) were collected by excision, stored in 50:50 glycerin and water with a small amount of thymol, and read under magnification with reflected light on a black background (Demory 1972; Mearns and Harris 1975; Hayman and Tyler 1980; Kreuz et al. 1982). Both scales and otoliths provided satisfactory estimates of age for young and fast-growing fish up to age 5 for males and age 6 for females (Demory and Pikitch 1986). After age 5, Pikitch and Demory (1988) calculated that the underestimation worsens with advancing age. For older specimens, Chilton and Beamish (1982) recommended counting annuli on a cross section of the otolith, since surface counts on scales and otoliths tended to underrepresent advanced ages. Demory and Pikitch (1986) recommended that the broken-and-burned otolith method (Christensen 1964) be used to replace the scale method for the routine aging of Dover sole. Their otoliths were stored dry or in 30%-50% ethyl alcohol.

The weight of a Dover sole increases by the cube of its length. Both males and females closely approximate this "cubic law," though males gain weight at a slightly slower rate (Hagerman 1952). Dover sole are about 11.4 cm long at age 2, and begin to enter the commercial trawl catch by age 4 at about 24.1 cm TL and a weight of about 136 g. By age 8 they are about 35.5 cm long, weigh about 450 g and are fully recruited to the trawl fishery (Demory 1975). Differential growth between male and female Dover sole becomes apparent near age 5 (Figure 7). The difference continues throughout the life of the fish: at age 20, females average 53.3 cm TL in length and weigh 1,452 g, while males at the same age average 45.7 cm and 862 g (Demory 1975).

Annual growth rates of Dover sole vary by as much as 16%. These annual changes can be explained partly by changes in water temperatures at 100 m depth which, in turn, correlate with upwelling events (Figure 8) (Kreuz at al. 1982). The average age of Dover sole differs from port to port due to differences in the intensity of the local fishery and the relative year-class strengths in adjacent populations (Demory 1975). Demory (1972), who read the scales of 782 Dover sole captured off the Columbia River, found the maximum age to be 24 years. Subsequently, Demory and Pikitch (1986) reported a maximum age of 37 years for male and female Dover sole using the broken-and-burned otolith method. Fish up to 45 years old were reported by Chilton and Beamish (1982), who examined cross sections of Dover sole otoliths. Barss and Demory (1988) reported a 46-year-old female and the recapture

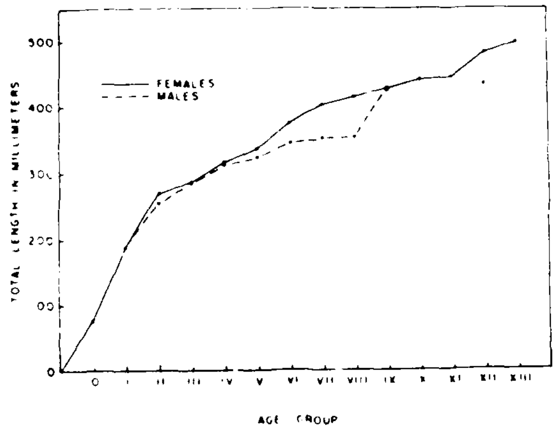

Figure 7. Length-age relation for Dover sole (Hagerman 1952). Note that Hagerman considers fish to be age 0 after 1 year of life.

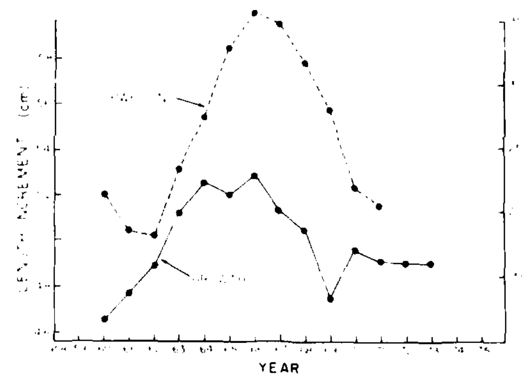

Figure 8. Five-year running average length increments for female Dover sole plotted against 5-year running average upwelling indices (Bakun 1973, 1975; Kreuz et al. 1982).

of a Dover sole that had been at liberty off Oregon for 22 years. These observations confirm the long life potential of the species.

Rock sole are generally aged by counting annuli on the interopercle or the otoliths. Interopercles are removed by excision, immersed in hot water for about 10 min, cleaned, and stored dry in suitable containers. Surface features of both interopercles and otoliths are examined under magnification and reflected light over a dull or dark background. For young fish, examination of the external otolith surface gives satisfactory results. For older fish, examination of the interopercle surface or burned cross sections of the otolith is necessary (Nishishimamoto 1985; Chilton and Beamish 1982). Fargo and Chilton (1987) validated the use of burned cross sections of rock sole otoliths for age determination.

The weight of rock sole, like that of the Dover sole and many other fishes, increases at a rate about equal to the cube of its length. Kaimmer et al. (1976) found that the overall length-weight relation for rock sole in the Bering Sea could be described by the equation:

$$W = 0.0078\ L^{3.136}$$

where W equals the predicted weight in grams of a fish L cm in TL.

Forrester and Thomson (1969) found that growth of rock sole in British Columbia occurs in two phases: in both males and females, the growth increment increases annually to age 4, and decreases annually from age 5 onward (Figures 9 and 10). Female rock sole reach 7-10 cm TL in 1.5 year, 22 cm in 3 years, and 35-39 cm in 5.5 to 7 years (Forrester 1969). Female rock sole grow faster than males and become longer (Nishishimamoto 1958; Alton and Sample 1976; Kaimmer et al. 1976). The largest rock sole recorded by Forrester (1969) was a 60-cm-TL female estimated to be 15 years old. A maximum age of 25 years was reported for rock sole by Chilton and Beamish (1982), who used the broken-and-burned otolith method.

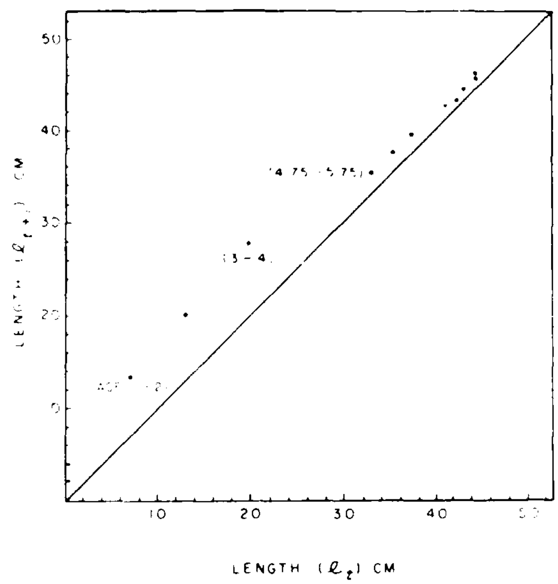

Figure 9. Walford graph of length of age t + 1 (age in years) against length at age t for female rock sole (Forrester and Thomson 1969).

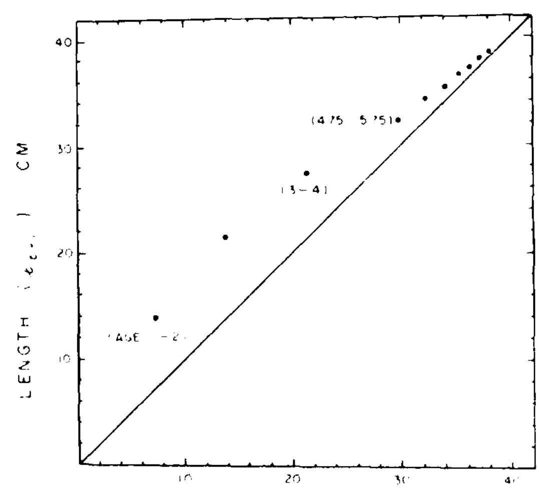

Figure 10. Walford graph of length of age t + 1 (age in years) against length at age t for male rock sole (Forrester and Thomson 1969).

Growth rate of rock sole varies from area to area and from year to year. Kaimmer et al. (1976) found absolute differences in the length-weight relations and between sexes of about 5%-10% among all areas sampled in the eastern Bering Sea. Levings (1967) found that rock sole from the British Columbia coast had a higher rate of growth than certain northern populations in the western Gulf of Alaska and northwest Bristol Bay. Nishishimamoto (1958) noticed great variation in the growth rate of rock sole from different locations in Puget Sound, Washington. Both Nishishimamoto (1958) and Forrester and Thomson (1969) cite density-dependent relations (in which growth rate decreases as density increases) as affecting growth of rock sole in some locations, and hydrographic conditions in others. In particular, Forrester and Thomson (1969) associated mean surface temperatures near 6.1 °C with better-than-average year-classes of rock sole (Figure 11). Whether temperature *per se* had a direct or indirect effect was not known. Forrester and Thomson (1969) also present data suggesting a density-dependent relationship among rock sole off central British Columbia.

ECOLOGICAL ROLE

Food and Feeding

Dover sole feed almost exclusively on benthic infaunal and epifaunal invertebrates, mainly polychaetes, ophiuroids, and mollusks (Pearcy and Hancock 1978; Gabriel and Pearcy 1981; Cross et al. 1985). Hagerman (1952) reported that no vertebrate had ever been found in the stomach of a Dover sole. Feeding on benthos is typical of flatfishes that have asymmetrical jaws, small stomachs, and long intestines (DeGroot 1971). Off Oregon, Dover sole feed most often on polychaetes of the families Pectinariidae, Glyceridae, Sternaspidae, and Opheliidae, in addition to Ophiuroidea. Amphipods--especially the genera *Harpiniopsis, Melphidippa, Ampelisca*, and *Nicipe*--are important crustacean prey. Pelecypods, particularly the genera *Macoma, Adontorhina*, and *Axinopsida*, make up most of the molluskan biomass consumed (Gabriel and Pearcy 1981).

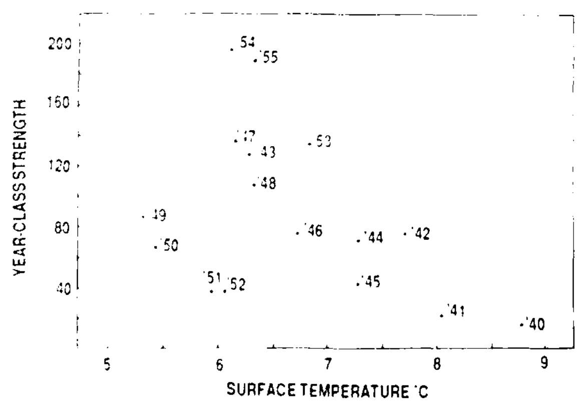

Figure 11. Relation between mean surface seawater temperature during February to April off Triple Island, British Columbia, and year-class strength of rock sole (redrawn from Forrester and Thomson 1969).

Annelids usually dominate in the diets of juvenile Dover sole in both summer and winter. Both juveniles and adults consume more prey in summer than in winter regardless of fish size (Pearcy and Hancock 1978). In general, Dover sole are not opportunistic feeders but tend to select food items. Larger Dover sole select larger prey and tend to feed in deeper water (Gabriel and Pearcy 1981). Pearcy and Hancock (1978) reported that Dover sole select habitats where their principal prey are most abundant, regardless of depth and bottom type.

Rock sole are predominantly benthophagous and feed mostly on benthic infaunal and epifaunal invertebrates. The principal prey off Oregon are ophiuroids of the genus *Ophiura*, polychaetes, pelecypods, sipunculids, and amphipods (Kravitz et al. 1976; Becker and Chew 1987). In Hecate Strait off central British Columbia, Forrester and Thomson (1969) listed polychaetes, crabs, shrimp, and clams as the most abundant items in the diet of 184 rock sole less than 29 cm TL. For fish longer than 29 cm, sandlance (*Ammodytes hexapterus*), crabs, shrimp, scallops, and herring were the principal prey consumed. Because the diet of fishes normally is related to feeding behavior, digestive tract morphology, and mouth structure (DeGroot 1971), the consumption of sandlance and herring may be unusual. The mouth of rock sole is small; the jaws and dentition are better developed on the blind side; the teeth

are bluntly conical; and the gill rakers are without teeth (Kravitz et al. 1976).

ENVIRONMENTAL REQUIREMENTS

Substrate

The Dover sole is a deep-water species and shows a strong preference for mud or silt bottom (Demory et al. 1976b; Barss et al. 1977; Pearcy 1978). In their study area off Oregon, Pearcy and Hancock (1978) concluded that depth-related factors had a greater influence than sediment type on the composition of benthic fishes, fish food, and invertebrate fauna. There was a shallow-water and deep-water association in the composition of the diet of Dover sole in their study.

Temperature

Dover sole appear to grow most rapidly during spring and summer months off Oregon (Demory 1972; Kreuz et al. 1982). Seawater temperatures at 50 m and 150 m are coldest during these months and were not significantly correlated with growth of Dover sole (Kreuz et al. 1982). However, the annual changes in growth rate for Dover sole are explained partly by lower water temperatures that are correlated with upwelling (Kruse 1981; Kreuz et al. 1982).

Environmental temperature may be an important contributor to variations in year-class strength. Forrester and Thomson (1969) presented data indicating that year-classes were better than average at temperatures near 6 °C, and poorer than average at higher or lower temperatures (Figure 11). Ames et al. (1978) determined that 24.9 °C was the upper lethal water temperature at which 50% of the rock sole survived.

Currents and Upwelling Events

Hayman and Tyler (1980), after investigating the influence of various environmental factors on Dover sole cohort strength, concluded that the strength of one cohort is positively correlated with the strength of the next cohort. For example, strong cohorts tend to be followed by strong cohorts. Spawning capacity (which is the egg production of a population) did not significantly affect cohort strength of Dover sole (Hayman and Tyler 1980, Hayman et al. 1980). The critical environmental period occurs from September of the year before hatching until May of the year after hatching. Cohort strength was not correlated with north-south water transport but rather with east-west water transport, which is associated with upwelling and, in turn, with food availability for larvae in June and July. Cohort strength just before and during settling of larvae was highly correlated with the offshore divergence index, which measures the acceleration of surface water transport at a point (Bakun 1973, 1975; Hayman and Tyler 1980). The offshore divergence index is correlated, in turn, with the convergence of inshore and offshore currents, which may be beneficial if they confine larvae to the area of the Continental Shelf where favorable habitat is available for them to settle (Hayman and Tyler 1980).

Depth

Rock sole occupy relatively shallow water throughout their range. In waters of British Columbia and the Gulf of Alaska, the species is most common on the inner continental shelf at depths less than 91 m (Alton and Sample 1976). In the Alaska Peninsula region, they occurred in 40% to 87% of the trawls on the inner shelf and were the dominant flounder (Alverson et al. 1964). Throughout the Aleutian Islands region, rock sole are common from 100 to 300 m and occasionally are found at 500 m (Ronholt et al. 1986). In the eastern Bering Sea, rock sole occur from shallow waters to depths of 200 to 300 m (Alton and Sample 1976).

Parasites

Encysted nematodes in the mesenteries and on the liver were reported for Dover sole examined in northern California (Hagerman 1952).

Rohde (1984) reported that the nematode *Philometra* occurs between the rays of the dorsal and ventral fins and subcutaneously in the opercular region, gill cavity, and occasionally the caudal fin of rock sole. The parasites are always coiled and immobile. To extrude embryos, the female worm must bore through the host integument.

Disease

Skin tumors were observed in Dover sole throughout a broad geographic area. Allen and Mearns (1976) list fin erosion and tumors as affecting Dover sole captured off southern California near sewage outfalls. Cross (1985) collected Dover sole in the same area from 1971 through 1982 and found that 34% of the specimens had fin erosion. The incidence of the disease was negligible in new recruits 40-50 mm SL, but increased rapidly with increasing fish size. Cross (1985) found no significant difference in the length-weight relation or size-at-age data between Dover sole with and without the disease; however, survival rate of fish older than 3 years was significantly lower. Sinderman (1979) reported that fin rot is the best known but least understood disease of fish from polluted waters.

The number of tumors per affected Dover sole captured off Ventura, Los Angeles, and Orange Counties, California, ranged from 1 to 10, with a mean of 1.8 (Mearns and Sherwood 1974). Histopathological examination of the tumors indicated that the growth included *angioepithelial nodules and epidermal* papillomas (Wellings et al. 1965). The presence of tumors appeared to be a function of fish size--usually occurring in specimens less than 150 mm SL (Mearns and Sherwood 1974). While tumors have been associated with decreased growth and increased mortality in flathead sole (*Hippoglossoides elassodon*) (Miller and Wellings 1971), the actual fate of tumor-bearing Dover sole has not been determined (Mearns and Sherwood 1974).

As with Dover sole, skin tumors were observed in rock sole throughout an extensive geographic area. Alton and Sample (1976) reported that the incidence of skin tumors is higher in eastern Bering Sea rock sole than in other groundfish examined. In 1975, 1% of the fish sampled had tumors; the tumors were found only on the blind side of the fish. Peters (1984) found that up to 10% of the rock sole in the Bering Sea were infected with X-cell papillomatosis. Levings (1967) reported that about 10% of the rock sole captured in the western Gulf of Alaska and in northwest Bristol Bay were infected with a tumorous growth. Malins et al. (1984) reported the presence of lesions in the liver, kidney, and gills of rock sole captured in Puget Sound, Washington. The lesions were either associated with parasites and microorganisms or were of unknown etiology. The idiopathic lesions were correlated with the presence of a wide assortment of accumulated chemicals and compounds in the sediments; specific cause and effect relations were not identified (Malins et al. 1984).

THE FISHERY

Dover sole are caught with an otter trawl dragged on the bottom by a single vessel (Demory 1975; Hayman et al. 1980). Areas of major abundance are found off northern California, central Oregon, and the Columbia River; areas of lesser abundance are found off northern Washington and British Columbia. The 10-year average trawl catch of Dover sole off Washington, Oregon, and California for the period 1972-86 is shown in Table 1.

Table 1. Ten-year average trawl catch (in thousands of *pounds*) of *Dover sole off* Washington, Oregon, and California, 1963-86. Data from Annual Reports 22-38 of the Pacific Marine Fisheries Commission (PMFC 1969-85), and Korson and Silverthorne (1987).

	State		
Period	WA	OR	CA
1963-72	1,612	4,846	12,023
1964-73	1,459	4,753	13,294
1965-74	1,419	4,761	14,275
1966-75	1,404	4,875	15,467
1967-76	1,578	5,042	16,713
1968-77	1,709	5,067	18,141
1969-78	1,884	5,380	19,513
1970-79	2,430	5,945	20,564
1971-80	2,450	6,271	20,923
1972-81	2,739	6,873	21,534
1973-82	3,217	6,871	21,525
1974-83	3,742	9,484	21,124
1975-84	4,339	10,269	19,214
1976-85	4,834	11,039	21,481
1977-86	4,701	11,022	21,862

Rock sole are captured in trawl fisheries in the Pacific Northwest (PMFC 1969-85). The 10-year average trawl catch of rock sole off Washington, Oregon, and California for the period 1972-85 is given in Table 2.

The largest catches of rock sole have been taken from the eastern Bering Sea and the Aleutian Islands region. Rock sole were captured in the eastern Bering Sea by Asian trawlers as early as 1933 and were intensively harvested by fleets from Japan and the U.S.S.R. in 1960 and 1961 (Alton and Sample 1976). The early fishery was conducted with longlines, gill nets, and dragnets, and most of the catch was processed into fish meal by the Japanese. By 1972, as many rock sole were frozen for later consumption as were reduced to fish meal (Alton and Sample 1976). Historically, Japan, the U.S.S.R., and the Republic of Korea were the predominant harvesters of rock sole in the eastern Bering Sea. Beginning in 1980, U.S. fleets began operations for groundfish in this area. In 1987, U.S. fisheries were projected to take 95% of the total catch (Bakkala 1987), most of which was frozen. The all-nation catches, the estimated biomass, and the estimated maximum sustained yield for rock sole in the eastern Bering Sea and the Aleutian Islands region are given in Table 3.

Table 2. Ten-year average trawl catch (in thousands of pounds) of rock sole off Washington, Oregon, and California, 1963-85. Data from Annual Reports 22-38 of the Pacific Marine Fisheries Commission (PMFC 1969-85).

10-year mean	State WA	OR	CA
1963-72	949	23	2
1965-74	950	24	4
1966-75	902	26	6
1967-76	805	26	7
1968-77	659	27	8
1969-78	613	24	9
1970-79	250	10	5
1971-80	244	12	5
1972-81	232	8	5
1973-82	218	7	6
1974-83	189	11	6
1975-84	159	11	6
1976-85	312	21	14

Table 3. All-nations catches, estimated biomass, and maximum sustained yield (MSY) estimates in metric tons for rock sole in the eastern Bering Sea and Aleutian Islands region of Alaska (odd years only). (Data from Walters and Halliday 1987a.)

Year	Catch	Biomass	MSY
1963	5,029	—	—
1965	3,825	—	—
1967	4,789	—	—
1969	9,242	—	—
1971	40,420	—	—
1973	23,837	—	—
1975	12,014	175,500[a]	—
1977	2,914	—	—
1979	1,468	194,700[a]	—
1981	9,021	302,400[a]	—
1983	13,618	934,500	—
1985	37,678	720,300[a]	70,000
1987	—	1,249,800[a]	100,000

[a]Eastern Bering Sea only

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15. Supplementary Notes

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal species. Dover sole are found in deep waters and prefer silt to muddy-sand bottoms; rock sole occur in shallow waters on soft to firm bottoms. Dover sole mature at about 5 to 7 years and spawn buoyant eggs from November to April; rock sole mature at 3 to 5 years and spawn demersal and adhesive eggs during winter and spring. Dover sole begin benthic life at age 1 and rock sole at 20 mm SL. Dover and rock soles migrate to shallower waters for the summer and to deeper waters for the winter; neither exhibits significant north-south movements. Dover sole live to 46 years and rock sole to 25 years; broken and burned otoliths are used to age both fish. Dover and rock soles feed on benthic infaunal and epifaunal invertebrates. Throughout a wide geographic area both species are affected by skin tumors. These soles are harvested commercially with trawls; northern California and Oregon are the main areas for Dover sole, while the eastern Bering Sea and Aleutian Islands are most important to rock sole.

17. Document Analysis a. Descriptors

Flatfishes	Feeding habits	Temperature	Fisheries
Life cycles	Depth	Growth	Sediments
Contaminants			

b. Identifiers/Open-Ended Terms

Dover sole	Environmental requirements
Microstomus pacificus	Rock sole
Lepidopsetta bilineata	

c. COSATI Field/Group

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